

# **SOFish ver. 1.2 - A Decision Support System for Fishery Managers in Managing Complex Fish Stocks**

**A K Supriatna<sup>1\*</sup>, A Sholahuddin<sup>1</sup>, A P Ramadhan<sup>1</sup> and H Husniah<sup>2</sup>**

<sup>1</sup>Department of Mathematics, *Padjadjaran University*, Sumedang 45363, INDONESIA

<sup>2</sup>Department of Industrial Engineering, *Langlangbuana University*, Bandung 40261, INDONESIA

E-mail: aksupriatna@gmail.com

**Abstract.** Sustainability is an important issue in a fishery industry. A manager of the fishery industry is responsible in deciding the best harvest that is able to sustain the industry while it should also guarantee the profitability of the industry. The most used concept in determining the best harvest in many fisheries industries is the Maximum Sustainable Yield (MSY). It represents the maximum amount of biomass that can be taken out from the fish population without harming the sustainability of the fishery. In other words, it is used to keep the population size stay over a threshold value of population level whenever harvesting activities is going on until indefinite time. In this paper we discuss a Decision Support System (DSS) for fishery managers in estimating the best harvest in a fishery industry. The best harvest is known as the Maximum Sustainable Yield (MSY) of the fishery. The DSS produces the MSY based on the discretization of some mathematical models of population growth, including the most popular models, such as Verhulst, Gompertz and Richards models. We also adding a biological complexity into the models, i.e. the presence of various degree of intra-specific competition of the population, which enhances the realism of the model and the DSS..

## **1. Introduction**

Sustainability is an important issue in a fishery industry. A manager of the fishery industry is responsible in deciding the best harvest that is able to sustain the industry while it should also guarantee the profitability of the industry. The most used concept in determining the best harvest in many fisheries industries is the Maximum Sustainable Yield (MSY). It represents the maximum amount of biomass that can be taken out from the fish population without harming the sustainability of the fishery. In other words, it is used to keep the population size stay over a threshold value of population level whenever harvesting activities is going on until indefinite time.

The awareness among fisheries managers about the excessive of fish exploitation, its extinction issue, and fisheries population dynamic has created a demand for highly reliable software in the form of a decision support system (DSS). There are many examples of the use

---

\* To whom any correspondence should be addressed.



of the DSS in fisheries industries, such as described in [1-5]. The software is usually directed for computing several complex mathematical processes that guides the user to take a proper decision that support population sustainability in managing the fisheries, e.g. by giving the right estimation of the MSY.

Knowing the amount of biomass of a fishery stock, at least its growth parameters, is regarded as an effective way in order to sustain the fish or aquatic populations in the fishery, since the MSY is a function of these growth parameters. In order to find the right value of the MSY, a DSS application needs a mathematical model used as the bases for the MSY calculation. In this paper we propose an integrated DSS using several different mathematical models as the bases for the MSY calculation. The models are continuous growth models, so to run the process in the computer, we discretize the models in terms of yield and effort variables to process the data input. There are two discrete forms for each models generated in the computation. These two discrete forms, in terms of yield and effort variables, are used as the bases for computing the intrinsic growth rate  $r$  and the carrying capacity  $K$  parameters. A Multiple linear regression with ordinary least square (OLS) method is needed to find these growth parameters, which are the main ingredient in obtaining the value of the MSY. The DSS is intended as the improvement of the previous version (SOFish ver. 1.0 [6] and SOFish ver. 1.1 [7]).

The rest of this paper consists of four sections and organized as follows. Section 2 introduces the mathematical models used in the development of the DSS. The main difference between the known mathematical models with the models in this paper is that here we consider a more complex biological interaction of the fish stock, where we assume that it has intra-specific competition between individuals in the fish stock. Section 3 discusses the design of the DSS followed by a case study using a known fishery data set in literature. Section 4 furnishes the concluding remarks of the research.

## 2. The Mathematical Models

It is known in literatures that to estimate the growth parameters in a continuous population model we can discretize the model in several different ways [1]. Here we consider a parameterization of four different well known models, the Verhulst growth model (1), the  $\alpha$ -Verhulst growth model (2), the Richards growth model (3), the Gompertz model (4), the  $\alpha$ -Gompertz growth model (5), and the generalized Gompertz growth model (6), as seen in the first two columns of Table 1. The appearance/disappearance of  $\alpha$  in the different position reflects the different biological behaviour of the population, e.g.. the degree of intra-specific competition of the population. Here the growth parameters  $r$  and  $K$ , respectively, represent the intrinsic growth rate parameter and the carrying capacity parameter of the stock/population. Now, suppose there is a constant rate of harvesting  $C$ , then the dynamics of the exploited population for the Verhulst growth model (1) is given by  $dX/dt = rX(1 - X/K) - C$  and for the Gompertz growth model (4) is given by  $dX/dt = rX \ln(K/X) - C$ . All other models follow the same pattern. In this new system, i.e. in the harvested system, sustainability can be achieved when the growth of the harvested population is non-negative. The easiest one is when the exploited population is at its equilibrium population size, i.e. when  $dX/dt = 0$ . This steady-state condition ensures the sustainability of the stock in the long term, and at the same time it gives the harvest as a function of stock abundance, i.e.  $C = f(X, \alpha, r, K)$ . The maximum

value of  $C$  that is able to maintain the population at certain sustainable level is called the Maximum Sustainable Yield (MSY). Upon executing the same standard procedure, in the last two columns of Table 1, we obtain the MSY's for equations (1) to (6) given by expressions (7) to (12), respectively.

**Table 1.** Growth equations and their respective MSY's.

Growth equation	eqn. no.	MSY	eqn. no.
$dX/dt = rX(1 - X/K)$	(1)	$\frac{rK}{4}$	(7)
$dX/dt = rX(1 - X^\alpha/K)$	(2)	$r\left(\frac{K}{1+\alpha}\right)^\frac{1}{\alpha}\left(1 - \frac{1}{1+\alpha}\right)$	(8)
$dX/dt = rX(1 - X^\alpha/K^\alpha)$	(3)	$r\left(\frac{K^\alpha}{1+\alpha}\right)^\frac{1}{\alpha}\left(1 - \frac{1}{1+\alpha}\right)$	(9)
$dX/dt = rX \ln(K/X)$	(4)	$\frac{rK}{e}$	(10)
$dX/dt = rX \ln(K/X^\alpha)$	(5)	$re^\alpha^\frac{1}{\ln K - 1}$	(11)
$dX/dt = rX \ln(K^\alpha/X^\alpha)$	(6)	$\alpha re^\alpha^\frac{1}{\ln K - 1}$	(12)

In practice, to obtain the value of the MSY directly from the continuous models is a difficult task. Because known fishery data is discrete and often measured in Catch per unit Effort (CPUE), and it is not measured in the population density  $X$ . Here we arrive at two complexities: the first one is dealing with transforming the continuous models into the discrete one, and the second is dealing with transforming the known data (Catch and Effort data) into the population density variable  $X$ . This task is challenging and involved some mathematical complexities and sophistication, which some managers try to avoid. We omit the detail derivation of the discretization, instead we propose a DSS that can be easily operated by fisheries managers to compute the MSY from the available catch-effort data they have at hand.

Some mathematical investigation have been undertaken resulted in fruitful theory of harvesting [8-25] and some still on-going pursuing some insight in many direction of research, e.g. by improving the realism of the model in terms of coupled sub-populations and in terms of intra-specific competition within sub-populations [26,27]. In this regards, our DSS is built in the endeavour to help the manager in deciding the best policy (i.e. determining the level of harvesting that can sustain the fishery in the long-run), without relying in a depth mathematical comprehension of the theory as the prerequisite. The DSS especially has a rich feature in terms of intra-specific competition of the underlying fishery populations, encompassing major well-known sigmoid shape population growth models.

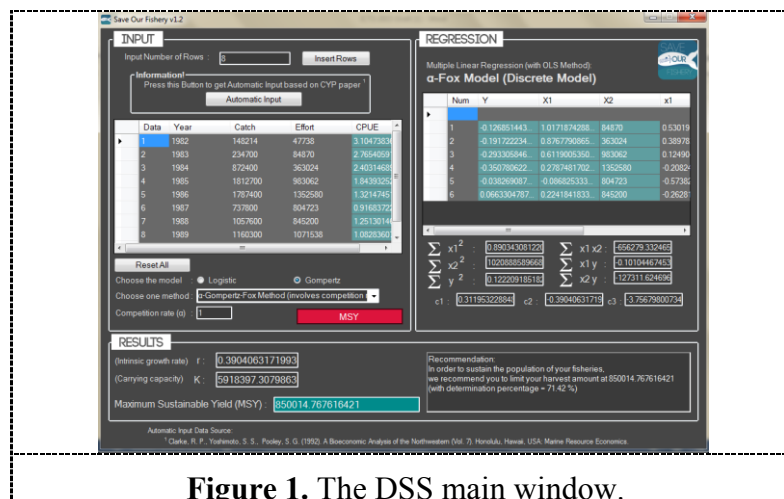
### 3. The Decision Support System

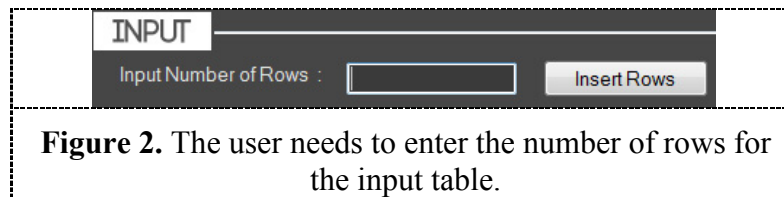
The potential of a DSS as computerized tools in assisting decision-making process has been attracting many researchers for the last fifty years to improve decisions in many decision problems [28], especially for those complex problems. The issue has also been attracting many harvesters as the manager in fishery industries as explained in the introduction. In implementing the harvesting models in the DSS, here we develop discrete forms of the

models shown in equations (1) to (6). The population density variable ( $X$ ) in the model is transformed into the catch ( $C$ ) and effort ( $E$ ) variables via the relation  $C=qEX$ , where  $q$  denotes the catchability coefficient. The only data used as the input to run the DSS is the time series of  $C$  and  $E$ . This data is analysed using the ordinary least squares method for multiple linear regression to produce the MSY level for the respected model chosen in the DSS. The implementation of a prototype of the DSS was built in Visual C# for windows form application. In the previous study [1] we used several software that have a capability to perform the OLS in order to check the validity of some computational outputs. In order to make a good and fair comparison between the previous DSS prototype and the new one, we adopt the previous feature but make some improvement in several fields to the system, especially for the mathematical models or methods.

In the development of the DSS, the code used for the computational process of the OLS has been programmed manually. We do not use any library or any kind of plug-in that able to perform the multiple linear regression automatically. We choose this way in order to implement a step-by-step procedure of the mathematical process of the OLS, so that it will be easier to modify in the future when needed. We design the physical appearance of the DSS as simple as possible, where the main window is organized in single— compact sub-windows form with three major functional panels: Input data panel, regression panel and results panel as shown in Figure 1. The first step to do to use the DSS is to input the data needed in the MSY calculation into a number of rows. This can be done by pressing the “Insert Rows” button to reserve the number of rows depending the number of data we have (Figure 2). The automatic input button is available to use a pre defined data as an example in the MSY calculation with known MSY in the literature.

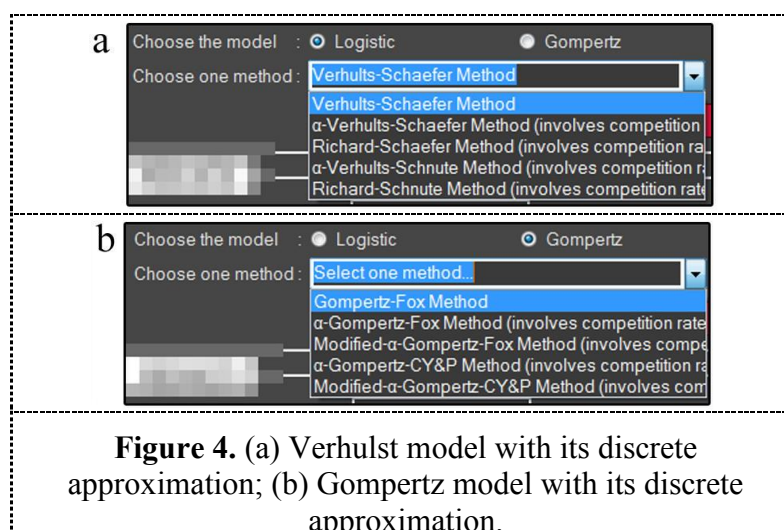
The next functional area is the input table. The availability of space depends on the number of rows that has been reserved in the previous step. In the table sheet, there are five columns with different headers that correspond to different categories: order or data id number, year, catch, effort, and Catch per unit Effort (CPUE). The DSS uses a Catch and Effort data in order to find the value of the MSY as a final consideration to the primary user. Catch and Effort data were required in order to continue the process of computation. The CPUE column would be filled automatically, right after one of mathematical model and method has been selected respectively in the option and the computation processes has been executed by the user. This characteristic makes the functionality of the table proceed as well as a spreadsheet. The user could execute them by clicking the MSY button and all required fields have completely filled before.

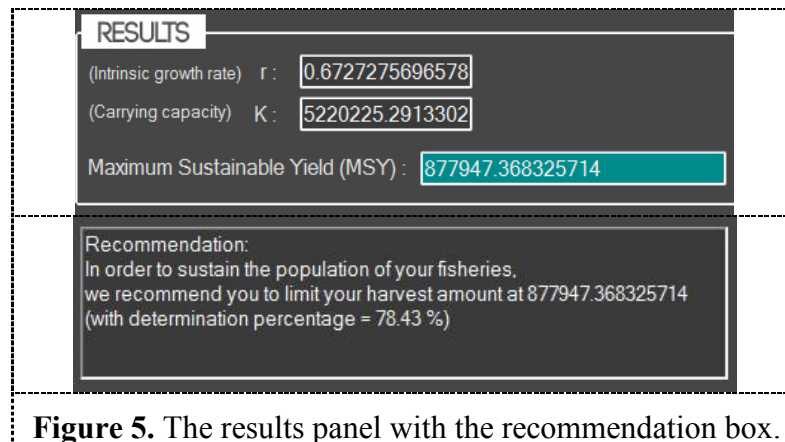




The users also have to choose between two options of mathematical models, namely Verhulst and Gompertz family models. If the user considers to choose one of the Verhulst models in equations (1) to (3), there would be five options for the discrete approximation of Logistic model. There were Verhulst-Schaefer,  $\alpha$ -Verhulst-Schaefer, Richards-Schaefer,  $\alpha$ -Verhulst-Schnute and Richards-Schnute method on the selection box (Fig. 4.a). On the other hand, if the user considers to choose one of the Verhulst models in equations (4) to (6), then Gompertz-Fox,  $\alpha$ -Gompertz-Fox, Modified-  $\alpha$ -Gompertz-Fox,  $\alpha$ -Gompertz-CYP and modified- $\alpha$ -Gompertz-CYP methods would come as the five options for the Gompertz model (Fig. 4.b).

The last four options for each model came as the improvement in this new version of the DSS, which is a distinct feature in the current version of the DSS and is not available in many known DSS model for fishery managers. In addition, almost all of the methods involve competition rate  $\alpha$  to enhance the robustness of the model. The discrete approximation would be used for the computational processes of multiple linear regression with OLS in order to estimate the intrinsic growth rate  $r$  and carrying capacity  $K$ . The output of the OLS would be shown in the regression panel. In this panel, the user would find the regression coefficients that will be used to calculate the three growth parameters,  $r$  and  $K$ . The growth parameters would be used to find the MSY value. The value of each parameters and MSY would appear respectively in the results panel with the recommendation box that comes as suggestion for the user.





**Figure 5.** The results panel with the recommendation box.

#### 4. Implementation and Discussion

In the DSS we use the discrete version of equation (1) derived by [14] (Verhulst-Schaefer method) and by [23] (Verhulst-Schnute method). We follow the method in [14] and [23] to derive the discrete version of equation (2), to obtain the  $\alpha$ -Verhulst-Schaefer and the  $\alpha$ -Verhulst-Schnute methods. Analogously, we use the discrete version of equation (4) derived by [29] (Gompertz-Fox method) and by [24] (Gompertz-CYP method). We also follow the method in [29] and [24] to derive the discrete version of equation (5), to obtain the  $\alpha$ -Gompertz-Fox and the  $\alpha$ -Gompertz-CYP methods. The discrete equations can be seen in [7]. To test the software we use the data set in [24], because the MSY is already known in [24] for the reason of comparison. The results in Figure 5, uses the data set in [24], and the value of the resulting MSY in Figure 5 is exactly the same as in [24]. This indicates that the DSS is in agreement with known method, with the addition that in the DSS we can find the best  $\alpha$  that fits the data, not necessarily 1 as in the known literature. This system need to improve in the future considering that there are some other biological complexities found in nature beside those treated in this paper, e.g. the metapopulation structure of the fish stocks. This is currently under investigation.

#### Acknowledgments

Authors wish to acknowledge financial support from the Indonesian Government through the scheme of Sinas Ristek 2015 and the travel grant from the ALG program.

#### References

- [1] Alagappan M and Kumaran M 2013 Application of expert systems in fisheries sector – a review *Res. J. Anim. Vet. Fish. Sci.* **1**(8) 19-30
- [2] Hughey K, Cullen R, Memon A, Kerr G and Wyatt N 2001 Developing a decision support system to manage fisheries externalities in New Zealand's exclusive economic zone *Microbehaviour and macroresults: Proc. Ten Bienn. Conf. Int. Institute Fish. Econ. and Trade*
- [3] Lynch A J and Taylor W W 2013 Designing a decision support system for harvest management of Great Lakes Lake Whitefish in a changing climate *GLISA Project Reports* eds. Brown D, Bidwell D and Briley L (Available GLISA Center)
- [4] Teniwut Y K and Marimin 2013 Decision support system for increasing sustainable productivity on fishery agroindustry supply chain *Int. Conf. Adv. Comp. Sci. Infor. Sys.* (ICACSIS)
- [5] Truong T H, Rothschild B J and Azadivar F 2005 Decision support system for fisheries management *Proc. 2005 Winter Simul. Conf.* (IEEE Cat. No.05CH37732C), 1005

- [6] Ramadhan A P, Setiawan K E, Amriyati P and Supriatna A K 2014 Software development in estimating parameters for Logistic and Gompertz population growth models arising from a fishery problem *E-Proc. 2nd Int. Conf. Artific. Intelli. Comp. Sci.* pp. 110-119 (E-ISBN: 978-967-11768-8-7)
- [7] Supriatna A K, Ramadhan A P and Husniah H 2015 A decision support system for estimating growth parameters of commercial fish stock in fisheries industries *Procedia Comp. Sci. (elsevier)* **59** 331-339
- [8] Cunningham S 1981 The evolution of the objectives of fisheries management during the 1970's *Ocean Manage.*, **6** 251-278
- [9] Gordon H S 1954 The economic theory of a common-property resource: The fishery *J. Polit. Econ.* **62** 124-142
- [10] Ricker W E 1954 Stock and recruitment *J. Fish. Res. Board of Canada* **11** 559-623
- [11] Schaefer M B 1954 Some aspects of the dynamics of populations important to the management of the commercial marine fisheries *Bull. Inter-Amer. Trop. Tuna Comm.* **1** 27-56
- [12] Clark C W 1976 *Mathematical Bioeconomics: The Optimal Management of Renewable Resources 1st Edn.* (New-York: John Wiley)
- [13] Reed W J 1979 Optimal escapement levels in stochastic and deterministic harvesting models *J. Environ. Econ. Manage.* **6** 350-363
- [14] Schaefer M B 1957 A study of the dynamic of fishery for yellowfin tuna in the Eastern Tropical Pacific Ocean *Bull. Inter-Amer. Trop. Tuna Comm.* **2** 247-285
- [15] Conrad J M and Clark C W 1987 *Natural Resource Economics* (New-York: Cambridge University Press)
- [16] Munro G R 1992 Mathematical bioeconomics and the evolution of modern fisheries economics *Bull. Math. Biol.* **54** 163-184
- [17] Yodzis P 1994 Predator-prey theory and management of multispecies fisheries *Ecol. Appl.* **4** 51-58
- [18] Botsford L W, Castilla J C and Peterson C H 1997 The management of fisheries and marine ecosystems *Science* **277** 509-515
- [19] Mesterton-Gibbons M 1996 A technique for finding optimal two-species harvesting policies *Ecol. Model.* **92** 235-244
- [20] Supriatna A K and Possingham H P 1998 Optimal harvesting for a predator-prey metapopulation *Bull. Math. Biol.* **60** 49-65
- [21] Supriatna A K and Possingham H P 1999 Harvesting a two-patch predator-prey metapopulation *Nat. Resource Model.* **12** 481-498
- [22] Tuck G N and Possingham H P 1994 Optimal harvesting strategies for a metapopulation *Bull. Math. Biol.* **56** 107-127
- [23] Schnute, J 1977 Improved estimates from the Schaefer production model: theoretical consideration *J. Fish. Res. Board of Canada* **34** 583-603
- [24] Clarke R P, Yoshimoto S S and Pooley S G 1992 A bioeconomic analysis of the Northwestern Hawaiian islands lobster fishery *Mar. Resource Econ.* **7** 115-140
- [25] Verhulst P F 1838 Notice sur la loi que la population suit dans son accroissement *Corr. Mat. et Phys.* **10** 113-121
- [26] Supriatna A K and Husniah H 2015 Sustainable harvesting strategy for natural resource having a coupled Gompertz production function *Interdisciplinary Behavior and Social Sciences* ed. Gaol L (Leiden: CRC Press Balkema) chapter 16 pp. 91-95
- [27] Husniah H and Supriatna A K 2015 System dynamic approach in managing complex biological resources *ARPJ. Engineer. Appl. Sci.* **10** 1685-1690
- [28] Mohamad R, Hamdan A R, Othman Z A and Noor N M 2010 Decision support systems (DSS) in construction tendering processes *Inter. J. Comp. Sci.* **7** 35-45
- [29] Fox W 1970 Exponential surplus-yield model for optimizing exploited fish populations *Trans. Amer. Fish. Soc.* **99** 80-88